



Environmental and sustainability evaluation of livestock waste management practices in Cyprus

Lucía Lijó^{a,*}, Nicola Frison^b, Francesco Fatone^{b,c}, Sara González-García^a, Gumersindo Feijoo^a, Maria Teresa Moreira^a

^a Department of Chemical Engineering, Institute of Technology, Universidade de Santiago de Compostela, Spain

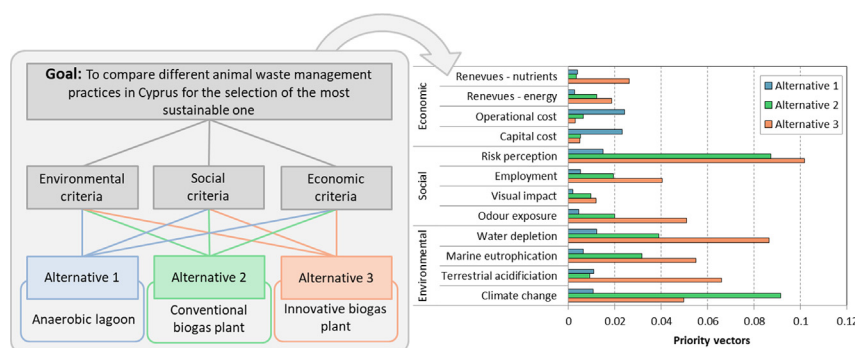
^b Department of Biotechnology, University of Verona, Italy

^c Department of Materials, Environmental and City Planning Science and Engineering, Faculty of Engineering, Polytechnic University of Marche, Ancona, Italy

HIGHLIGHTS

- Animal waste management practices were compared from a sustainable point of view.
- Different environmental, social and economic indicators were assessed and integrated.
- Life Cycle Analysis and Analytic Hierarchy Process were combined for multi-criteria analysis.
- The environmental performance of alternatives varied according to the impact category studied.
- Resource recovery from animal waste (biogas and biofertilisers) was the most sustainable approach.

GRAPHICAL ABSTRACT



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ABSTRACT

The aim of this study was to compare the environmental performance and sustainability of different management options for livestock waste in Cyprus. The two most common practices in the country, i.e. the use of anaerobic lagoons and conventional biogas plants, were compared with the innovative scheme developed in the LiveWaste project (LIFE12 ENV/CY/000544), which aims not only to produce bioenergy, but also to treat the digestate for nutrient recovery and water reuse. The Life Cycle Assessment (LCA) methodology was combined with the Analytic Hierarchy Process (AHP) to compare the performance of these alternatives. Four relevant indicators were selected for each dimension of sustainability (environmental, social and economic).

The results of the evaluations showed that anaerobic lagoons are not an appropriate option for the sustainable management of livestock waste due to environmental (e.g. climate change, acidification and eutrophication) and social impacts (e.g. noise exposure, visual impact and risk perception for human health). The most important strengths and weaknesses of anaerobic treatment with and without digestate treatment were identified. Compared to conventional anaerobic digestion where digestate is directly applied as an organic fertiliser, the technology proposed in the project entails higher technological complexity due to nitrogen removal and phosphorus recovery. The rise in chemical and electricity requirements increased the impacts on some indicators, such as

Abbreviations: AHP, Analytic Hierarchy Process; AS, alternative scenario; BTF, biotrickling filter; CC, climate change; CHP, cogeneration heat and power; CR, consistency ratio; CSTR, continuous stirred tank reactor; DF, dark fermentation; FD, fossil depletion; FE, freshwater eutrophication; FU, functional unit; GHG, greenhouse gas; LCA, Life Cycle Assessment; M1, methodology 1; M2, methodology 2; MCA, multi-criteria analysis; ME, marine eutrophication; NVZ, Nitrogen Vulnerable Zone; PROMETHEE, Preference Ranking Organisation Method for Enrichment Evaluations; POF, photochemical oxidant formation; RES, Renewable Energy Sources; SBR, Sequencing batch reactor; TA, terrestrial acidification; TOPSIS, Technique for Order Preference by Similarity to Ideal Solution; TVS, total volatile solids; VOC, volatile organic compound; WD, water depletion.

* Corresponding author.

E-mail address: lucia.lij@usc.es (L. Lijó).

climate change and operational cost (emissions of greenhouse gases and operation costs were around 50% higher), while reduced impacts in others due to proper nutrient management, as acidification and eutrophication impacts (which were 10 and almost two times lower, respectively).

For the specific Cypriot conditions, where the overapplication of nutrients leads to pollution of water bodies, the innovative treatment scheme with higher technological development presents an interesting approach. Nevertheless, the treatment of the digestate should be analysed taking into account the specific characteristics of each scenario.

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1. Introduction

Livestock management is a major global environmental problem, with significant impacts to air, water and soil as well as to biodiversity, as explained in the FAO report “Livestock’s long shadow” (FAO, 2006). It is estimated that in Europe manure management contributes with 65% to the total anthropogenic ammonia, 40% of nitrogen oxide and 10% of methane; in addition to direct nitrogen and phosphorus emissions to soil and water (Hou et al., 2017; Oenema et al., 2007). These burdens are directly related to outstanding environmental problems such as climate change, acidification and eutrophication. These environmental impacts have increased in recent years, particularly as a result of the current growing trends of intensification and specialisation in livestock production (Oenema et al., 2007). This problem is particularly relevant in Cyprus, where the introduction of intensive farming operations in recent decades has increased the amount of animal waste generated in specific areas, further aggravated by the insular nature of the country (Insam et al., 2014). More specifically, in this country animal waste represents 60% of biodegradable waste, 82% of which is piggery waste (Theofanous et al., 2014). According to Longo et al. (2016), the total production of livestock waste in Cyprus in 2013 was 1.6 million of tonnes of waste. Due to the large volumes of waste produced, it is not possible to apply it as organic fertiliser on the soil. To deal with its management, most small-scale pig and cattle farms use open evaporation lagoons for the management of their animal waste (Kythreoutou et al., 2012). In this type of treatment manure is sent to anaerobic lagoons, where the organic material is decomposed under anaerobic conditions, causing uncontrolled emissions of greenhouse gases (GHG) (i.e. methane, nitrous oxide) and other substances such as ammonia to the atmosphere (Kythreoutou et al., 2012).

Nevertheless, the number of biogas plants treating animal waste in Cyprus has increased in recent years to 11 units, which is attributed to the promotion of anaerobic digestion as a way to reduce environmental impacts and produce energy and biofertiliser from the digestate (Al Seadi et al., 2013). The production of renewable energy from organic waste is particularly desirable in Cyprus due to the characteristics of its electricity mix. Without interconnections of oil, gas or electricity, Cyprus has a completely isolated energy system, which is totally dependent on imported oil, contributing to 96% of the total primary energy supply (Theofanous et al., 2014).

Taking into account international environmental policies focused on the promotion of renewable energy consumption and the increasing prices of fossil fuels, the need to encourage Renewable Energy Sources (RES) in the current Cypriot energy system is becoming imperative. As a result, in recent years many RES production units have been installed in Cyprus (Theofanous et al., 2014). In 2013, 15% of RES was produced from photovoltaic systems, 75% from wind parks and 11% from biomass-biogas production units (Cyprus Energy Regulatory Authority, 2013).

Regarding the digestate produced by anaerobic digestion, it can be used with any further treatment other than storage during the spread season (Crolla et al., 2013). The storage, transport, handling and application of raw digestate as organic fertiliser imply significant costs for farmers, higher than its fertiliser value due to its large volume and low dry matter content (Rehl and Müller, 2011). The further treatment of the digestate can also contribute to compliance with the specifications

laid down in the Nitrates Directive (EEC, 1991) since Nitrogen Vulnerable Zones (NVZs) have been designated in Cyprus as a result of their high concentrations of nitrates in water. In this context, it is becoming crucial to develop innovative treatment schemes which, in line with the concept of circular economy, allow valuable products to be recovered from animal waste, such as renewable energy, nutrients and water. With this idea the LiveWaste project (LIFE12 ENV/CY/000544) was developed in Cyprus, co-financed by LIFE+ EU financial instrument in the thematic area of LIFE+ Environmental Policy and Governance in the priority area of Waste and Natural Resources. The project aimed to develop, demonstrate, optimise and evaluate an innovative combined system for the treatment of livestock waste with the aim of producing renewable energy, a reusable effluent, compost and struvite. Accordingly, the proposed treatment scheme addresses several environmental issues that not only Cyprus, but also other Mediterranean countries are facing today: i) livestock waste management, ii) renewable energy production, iii) water reclamation and iv) nutrients recovery.

As concluded in Martínez et al. (2009), to convert livestock waste treatment systems into sustainable processes, it is necessary to develop new methods that follow the principles of circular economy, shifting to a vision of recycling, including techniques that allow nutrient recovery. Before the implementation of these large-scale innovative systems, it is important to assess their potential environmental and sustainability performance (Hou et al., 2017). In this regard, the Life Cycle Assessment (LCA) is a generally accepted methodology which allows the environmental assessment of the proposed innovations before they reach full scale to anticipate possible problems and related solutions (Mininni et al., 2015).

This methodology has been widely applied to analyse the environmental performance and sustainability of several systems, including waste management technologies. Paccanelli et al. (2015) compared different nitrogen removal options for digestate from an environmental point of view: i) short-cut nitrification/denitrification and ii) partial nitrification and anammox. Prapasongsa et al. (2010) also evaluated the environmental consequences of 12 combinations of different options of storage, processing and application for pig manure. Eriksson et al. (2016) also performed the LCA of horse manure treatment, including anaerobic digestion, aerobic composting and incineration. De Vries et al. (2012) conducted a comprehensive LCA study on pig manure processing to produce bioenergy and a mineral concentrate. Beyond environmental analysis, other studies included the assessment of other pillars of sustainability, such as social and economic impacts. For example, den Boer et al. (2007) developed a methodology for the environmental, social and economic assessment of waste management systems in regions with rapidly growing economies. In some cases, the outputs of these studies are difficult to interpret because, due to the wide range of indicators, there may not be one fully satisfactory alternative (Angelo et al., 2017). Multi-Criteria Analysis (MCA) is an useful approach to decision-making when different indicators with different results can be obtained in the same framework (Angelo et al., 2017).

Combining LCA with MCA can be an interesting approach to implement LCA outcomes as environmental indicators. In this way environmental criteria can be integrated with social and economic criteria in a holistic way, analysing the sustainability performance of the system. In the available literature, different MCA methodologies have been

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